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Influence of Defects on the Ductility of Liquid 9X2MΦ and 75X3MΦ Steel

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Abstract—Viscosimetric data on liquid 9X2MΦ and 75X3MΦ steel taken from working rollers of a reversible rolling mill with different ultrasonic behavior illustrate the influence of defects recorded in ultrasound monitoring on the temperature and time dependence of the liquid steel's kinematic viscosity. A Krautkremer ultrasonic defectoscope is employed in monitoring. The viscosity of the liquid steel is measured by means of damping torsional oscillations of a crucible with melt in heating and subsequent cooling in the range 1500–1580°C.

Keywords: viscosity, ultrasonic monitoring, defects, steel

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Ultrasonic monitoring of the working rollers in a reversible cold-rolling mill reveals defects of the metal—cavities filled with gas or slag. We know that the reflection coefficient of ultrasound at the boundary of a gas-filled defect is close in amplitude to one; for a slag-filled defect, it is significantly less. Thin oxide layers give a weak reflected signal [1–4]. The sensitivity of ultrasonic monitoring, as a rule, corresponds to an equivalent defect diameter of 5 mm. According to the OST 24.023.33–86 standard, the presence of cavities with an equivalent diameter less than 7 mm is permissible. For example, over the barrel length of a 9X2MΦ steel roller, as a result of ultrasonic monitoring, a zone of defects with an equivalent diameter no greater than 4.5 mm was found at a depth of 120–350 mm; this is acceptable according to the OST 24.023.33–86 standard. In the same zone, numerous defects of limiting size were seen (Fig. 1).

Metallographic data on defective areas in rollers indicate an elevated content of nonmetallic inclusions, which form rows after rolling. Nonmetallic inclusions (oxides, sulfides, silicates) appear in steel components when refractory material enters the liquid metal or reduction products aggregate [5, 6]. Qualitative metallographic analysis shows the presence of nonmetallic inclusions (sulfides with a size score of 4 and complex oxides with a score of 5 according to State Standard 1778–70) in the zone of fatigue-failure propagation.

The relation between structural defects of metallic materials recorded by ultrasound monitoring and the structural state of the melt has not previously been discussed. For example, we know that nonmetallic inclusions in steel affect the fluidity of the melt, its solidification, and the acoustic characteristics of the steel components produced. However, the dependence of the ultrasound velocity on the structure of the cast metal has not been established. Therefore, it is difficult to judge the relation between the acoustic characteristics and the structure of the solid and liquid metal [2–4].

We have developed a promising method for improving the quality of 9X2MΦ and 75X3MΦ steel components: homogenizing heat treatment of the metallic melt [7]. This method yields metal with a minimum quantity of defects and does not require high rates of cooling [7–9]. The method is based on the assumption that, above the liquidus temperature,

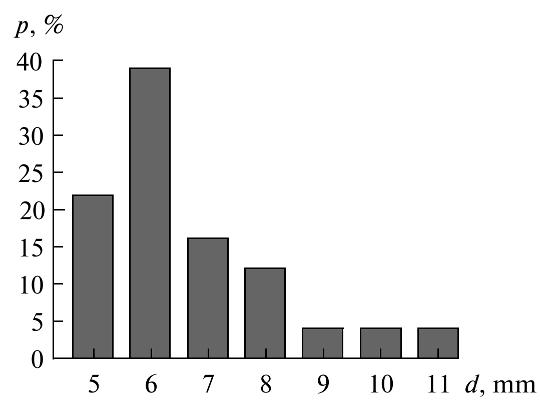

Fig. 1. Size distribution of defects.

microinhomogeneities whose chemical composition differs from that of the surrounding melt may exist for a long time in liquid metal. Their removal entails heating of the liquid metal to a temperature T_{hom}, which is different for each composition. After such heating, the melt returns irreversibly to the state of a true solution, which significantly changes its solidification conditions. Experiments show that breakdown of a microheterogeneous melt structure is usually accompanied by anomalous temperature dependence of the melt's properties—in particular, its viscosity. The temperature dependence of the melt viscosity is found to differ in heating and subsequent cooling. The temperature T_{hom} corresponding to irreversible transition to a homogeneous state is determined in this case from the onset of the high-temperature section where the heating and cooling polytherms are the same. In viscosimetric experiments with microheterogeneous melts, anomalously large spread of the kinematic viscosity is observed; often, it is not possible to correctly determine the kinematic viscosity for that reason. On heating to T_{hom}, this spread is irreversibly reduced to values corresponding to random measurement error.

In the present work, we investigate the relation between the structural characteristics of liquid 9X2MΦ and 75X3MΦ steel and the presence of nonmetallic inclusions smaller than 7 mm, which increase the damping of the ultrasonic waves. We propose melt-treatment conditions that improve the quality of the working rollers produced. Temperature and time dependences of the viscosity $\nu(t)$ are investigated for liquid 9X2MΦ and 75X3MΦ steel, so as to determine T_{hom}.

We investigate 9X2MΦ and 75X3MΦ steel samples taken from working rollers of a reversible rolling mill with different behavior in ultrasound monitoring. The 9X2MΦ steel contains 0.01–0.02% V, 0.25–0.50% Si, 0.2–0.3% Mo, 0.2–0.7% Mn, 1.7–2.1% Cr, and no more than 0.03% S. Working rollers are produced from 9X2MΦ steel forgings.

At OAO Uralmashzavod, such rollers are subjected to ultrasound monitoring, so as to detect cavities and other defects (cracks). A portable Krautkremer USM 35XS ultrasonic defectoscope is employed. The sensitivity of monitoring corresponds to an equivalent cavity diameter of 5 mm.

The viscosity is measured by means of damping torsional oscillations of a crucible with melt during the heating and subsequent cooling of the samples within the range 1550–1700°C. The temperature dependences are measured with isothermal holding (at least 30 min) and relatively small (10–15°C) stepwise temperature variation. The systematic error in measuring $\nu(T)$ is 3%, while the random error, determining the spread of the points within a single experiment, is no more than 1.5% at a confidence level $p = 0.95$. The time dependence of the viscosity is measured in individual experiments. At each temperature, 15–40 successive measurements are made. The temperature is maintained at the specified level to within 1°C by means of a high-precision regulator. In the measurements, the oscillations are recorded optically, by means of a specialized system. The experimental apparatus and methods for measuring the time and temperature dependences of the kinematic viscosity of melts and for analysis of the experimental data were described in detail in [10–12]. Samples for viscosimetric study were taken from working rollers of a reversible rolling mill from steel 9X2MΦ and 75X3MΦ with different damping of ultrasonic waves. In all the experiments, BeO crucibles are employed. Experiments are conducted in high-purity helium at 10^5 Pa.

The viscosimetric data for the 9X2MΦ and 75X3MΦ steel melts are shown in Fig. 2. For all the melts, supercooling by 50–60°C is observed. For 9X2MΦ steel samples with a defect structure, discrepancy between the heating and cooling polytherms (hysteresis) is observed: T_{hom} = 1540°C. For all the samples, increased (within 10%) spread of the kinematic viscosity is observed on heating (Fig. 2). Note that relaxation of the viscosity to some mean value is observed on heating for the sample with defects, but such relaxation occurs on cooling in the sample without defects. These findings indicate that overheating of the melt has a later influence on the inhomogeneity, on account of the defects in the initial ingot. We believe that, for 9X2MΦ steel, it is expedient to increase the melt temperature to 1540–1560°C—that is, to use homogenizing heat treatment.

The results may be interpreted in terms of the microheterogeneous structure of metallic melts [5]. Thus, on melting a multiphase steel ingot, what is formed is a solution of alloying elements in iron that is not immediately uniform at the atomic level. Within some temperature range, a microheterogeneous state is retained. Within the range where the microheterogeneity is sufficiently pronounced, instability of the viscosity is observed. Judging from the $\nu(T)$ curves, the transition of the melt to a true solution occurs close to the branching points. The temperature T_{hom} corresponding to irreversible transition to a homogeneous state may be determined from the onset of the high-temperature region where the heating and cooling polytherms agree. For liquid 9X2MΦ steel, T_{hom} = 1540°C (Fig. 2). After heating above T_{hom}, 9X2MΦ steel melt irreversibly becomes a true solution, according to [5]. That significantly changes the solidification conditions of the metal, even at industrial cooling rates, and marked improvement in properties of the cast metal may be expected.

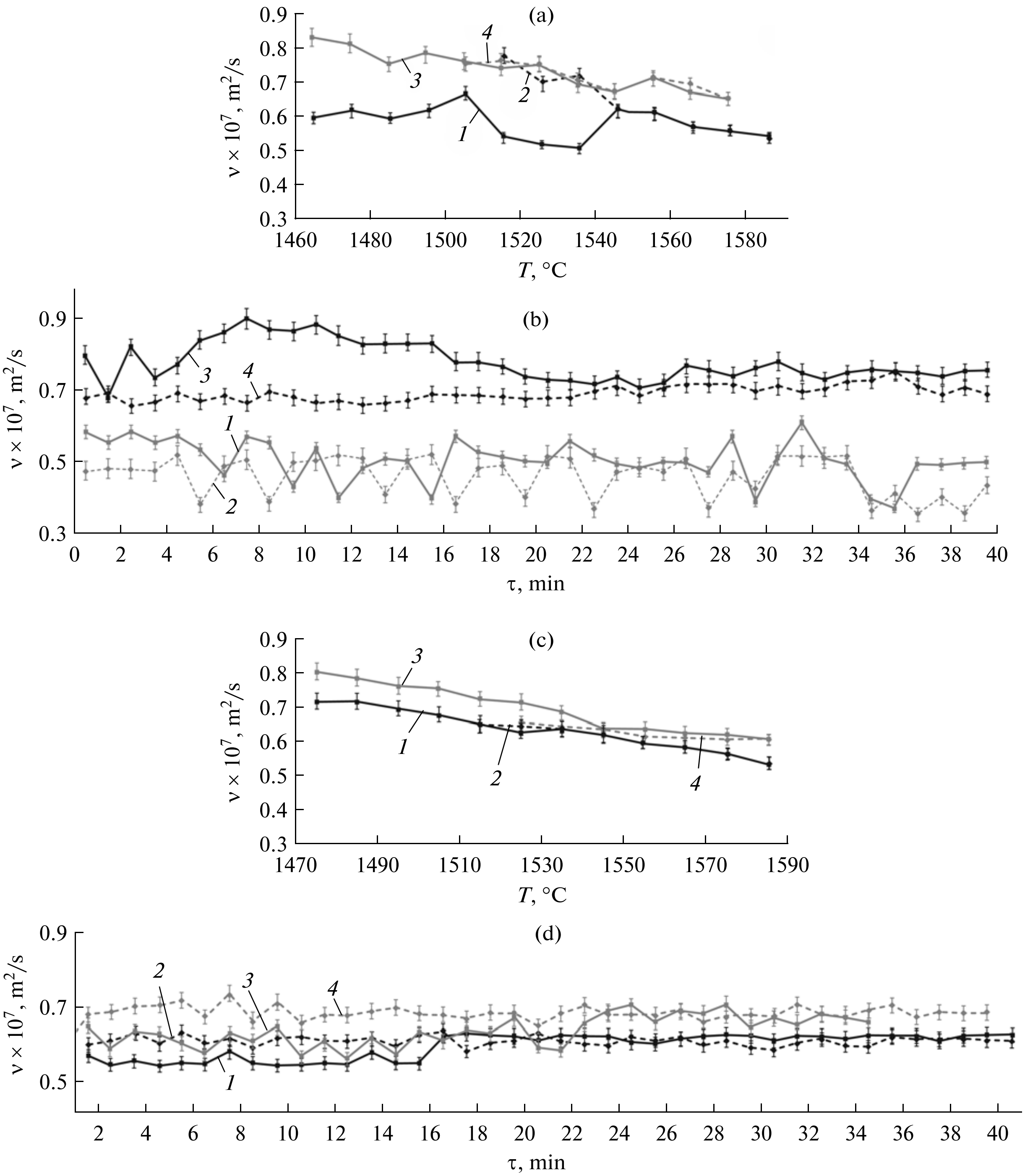

Fig. 2. Temperature and time dependences of the kinematic viscosity of liquid 9X2MФ and 75X3MФ steel taken from working rollers of a reversible rolling mill with different ultrasonic behavior: (a) 9X2MФ steel with defects on heating (*1*) and cooling (*2*) and without defects on heating (*3*) and cooling (*4*); (b) 9X2MФ steel with defects on heating (*1*) and cooling (*2*) at 1540°C and without defects on heating (*3*) and cooling (*4*) at 1540°C; (c) 75X3MФ steel with defects on heating (*1*) and cooling (*2*) and without defects on heating (*3*) and cooling (*4*); (d) 75X3MФ steel with defects on heating (*1*) and cooling (*2*) at 1540°C and without defects on heating (*3*) and cooling (*4*) at 1540°C.

CONCLUSIONS

Viscosimetric data on liquid 9X2MФ and 75X3MФ steel taken from working rollers of a reversible rolling mill with different ultrasonic behavior illustrate the influence of defects recorded in ultrasound monitoring on the temperature and time dependence of the liquid steel's kinematic viscosity.

For 9X2MΦ steel samples with a defect structure, discrepancy between the heating and cooling polytherms (hysteresis) is observed: $T_{hom} = 1540°C$.

At 1540°C, for all the samples, increased (within 10%) spread of the kinematic viscosity is observed on heating.

We recommend heating of 9X2MΦ steel melt to 1540–1560°C—that is, homogenizing heat treatment of the melt.

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